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Foundation Fieldbus Power Supply
A Look At Powering Fieldbus
by Analog Services, Inc.

Why should I read this?

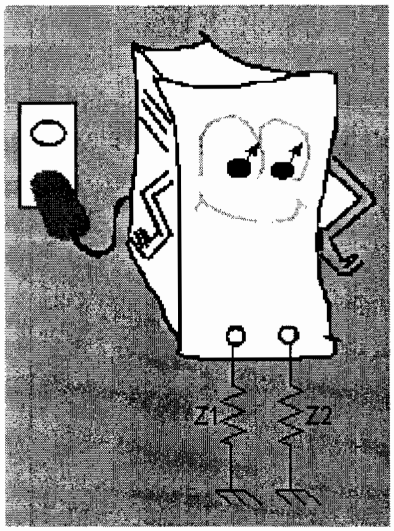
Because you're designing or using a **power supply** or **power** conditioner for Foundation **Fieldbus** or you're interested in getting **Fieldbus** to work. We've put together this question and answer sheet that might help. It talks about using both passive and active circuits to create **power** supplies having desired output impedances and impedances to ground. As always, your questions, comments, and corrections are welcome. You can download a MathCad file to do your own
calculations. Click here to download.

What's the big deal? Isn't a Power Supply just a Power Supply?

Not necessarily. Foundation **Fieldbus** needs a special **power supply** that has a modest output impedance at **Fieldbus** signaling frequencies, so that it won't short-circuit the signal. It also

requires a **supply** that is relatively well balanced with respect to ground. Powering multiple networks or using I.S. barriers introduces added complication. There may not be any one **power supply** solution that fits all situations.

A **Fieldbus Power Supply** is often created from a conventional or "raw" **power supply** by adding circuitry at its output terminals. The added circuitry establishes the correct terminal-to-terminal impedance, or it creates or improves balance with respect to ground. Or it may do both.



Z1 = Z2

Figure 1 -- Balanced **Supply**

What Does Balanced Mean?

It means that the **power supply** internal impedance from the (+) terminal to earth ground is ideally equal to the impedance from the (-) terminal to earth ground. This is illustrated in figure 1. Here, Z1 and Z2 are not added impedances or loads. Z1 represents the internal impedance from the (-) terminal to ground and Z2 represents the internal impedance from the (+) terminal to ground. They result primarily from the connection to the AC Mains. If we pull the plug, then Z1 and Z2 become almost infinite and would no longer affect **Fieldbus**. Earth ground is the **Fieldbus** cable shield. This usually translates into the **power supply** safety ground or an I.S. Barrier safety ground or a conduit or pipe.

Balancing doesn't happen automatically. Some **power** supplies have a connection from the (-) terminal to chassis, which means that they are entirely unbalanced. It's usually not difficult to get rid of this connection and achieve DC isolation. But there still may be a large amount of capacitance from either terminal to earth, so that the capacitance dominates the impedance. Z1 and Z2 of figure 1 are really a C1 and C2. This is why the **Fieldbus** Standard specifies capacitance unbalance. The capacitance unbalance is the difference between C1 and C2.

Either C1 or C2 is composed of a bunch of capacitances. Examples are the stray capacitance from terminal to chassis and the primary-to-secondary capacitance in the **power** transformer. If we try to measure the capacitance unbalance in a conventional or raw **supply**, it might seem to be almost perfectly balanced. But what we're actually seeing is the fact that there is zero impedance between the (+) and (-) terminals. Each measurement just gives us C1 in parallel with C2. So unbalance only has meaning in a **supply** that has a non-zero terminal-to-terminal impedance. Or, in other words, we have to look at the **Fieldbus Supply** in its entirety and not just a piece of it.

Notice, that as the **supply** becomes better isolated, C1 and C2 get smaller and their difference also gets smaller. So, one thing that improves balance is isolation. To a degree the balance can be inferred from the isolation. If it is known that the parallel combination of C1 and C2 is less than the specified unbalance, then the difference between C1 and C2 must also be less than the specified unbalance.

What Happens If I Don't Pay Attention To Balance?

An unbalanced **power supply** connected to a **Fieldbus** network will unbalance the network

An unbalanced **power supply** connected to a Fieldbus network will unbalance the network. This can lead to crosstalk and susceptibility to common-mode interference. This doesn't happen with analog 4-20 mA signaling because the frequencies involved are so much lower -- about 10 Hz versus 30 kHz.

OK, So What Are the Specifications?

There are two parts to the specification. The part that prevents short-circuiting of signals consists of clauses 22.6.3.1, 22.6.3.2, and 22.6.3.3. Instead of giving an impedance value, these sections specify a test setup. With minor variations, the test is the same for all three clauses and is shown in figure 2. For clarity, we left out some components that create a DC load for the **supply**.

The "**Supply** Under Test" can be anything that meets the spec. But we've shown it as a "Z" part in series with a raw (low impedance) **supply** because many of the methods to be discussed consist of these components or their equivalent.

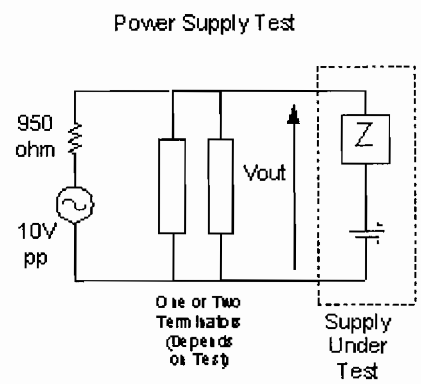


Figure 2 -- Test Circuit

We show the raw **supply** as a battery for convenience. Generally, in figure 2 and in the circuit diagrams to follow, the raw **supply** is an AC-Mains connected **supply**.

In the test the AC voltage magnitude across the **supply** (magnitude of Vout) is measured as frequency is varied. The voltage magnitude is expected to be in the range of 400 mV pp to 600 mV pp over a range of frequencies that depends on which test is being performed. In some cases there is an additional specification that the rate of change of measured voltage with frequency in the region of 50 Hz to 3 kHz is between -20 dB per decade and 20 dB per decade. We call this the Rate specification.

The maximum unbalanced capacitance to earth ground, specified in clause 22.6.5, is 250 pf.

We've created a MathCad program to calculate the output voltage magnitude (across the **supply** under test) under various conditions for the circuit of figure 2. It lets you use one or two terminators and a variety of component values for Z. You can download it by clicking here.

Where Did These Specs Come From?

The unbalance specification is the same as that for Field Instruments and is probably based on a desire that the **power supply** be not significantly different from a Field Instrument. The test setup of figure 2 is based on making the **power supply** and terminators look like about 50 ohm under a variety of circumstances. The Rate spec is an attempt to prevent significant ringing of **power supply** voltage in response to transients.

Clause 22.6.3.3 deals with connecting two or more networks together. It simply says that everything external to a given network must appear to that network as one terminator (100 ohms) at signal frequencies. And, of course, whatever is connected to the given network must also appear to be balanced with respect to ground.

Historically, in addition to the balancing considerations, the **supply** was simply supposed to present a relatively high impedance to the network. Instead of a test setup, an impedance value of > 3000 ohm (0.25 Fr to 1.25 Fr) was specified (clause 11.6.1). The change from simply trying to make the **power supply** look like a high impedance to making the combination

simply trying to make the **power supply** look like a high impedance to making the combination of terminators, etc. look like 50 ohm was prompted by a desire for **Fieldbus** devices that produce transient load current changes. That is, a **Fieldbus** device might increase its average current consumption while it transmits a **Fieldbus** message and then decrease its current back to a normal or quiescent level. The resulting current pulse may cause a low-frequency ringing in a network that uses just an inductor for Z. This ringing can either disrupt communication or cause other undesired effects. The specified rate of change of |Vout| (magnitude of Vout) with frequency is an attempt to try to prevent the ringing. Whether this works as intended is questionable, since a compliant **power supply**, when used with a network having substantial cable and device capacitance, can also ring at frequencies that are in-band. But this issue is outside of the scope of our discussion.

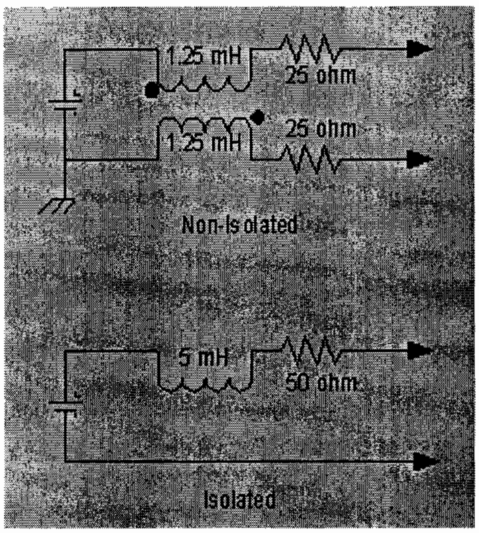


Figure 3 -- Possibilities For **Supply** Feeding Barrier

Simplest First: Supply Feeding Barrier

An intrinsic safety barrier (IS barrier) is a component used to build an intrinsically safe **Fieldbus** network. It is generally placed between a **power supply** and the network to limit current and voltage. A **power supply** used with a barrier has different **Fieldbus** requirements than a **supply** used without a barrier. From a specification viewpoint a **supply** that feeds a barrier is the simplest type, because it is the most completely specified. That is, there is not much choice as to what goes into Z of figure 2.

In the test of figure 2, this type of **power supply** has to produce the specified output (400 to 600 mV pp) over a frequency range of 50 Hz to 39 kHz. It turns out that a Z consisting of a 5 mH inductor in series with a 50 ohm resistor will, when combined with specified terminators, create a load that looks like 50 ohm at all frequencies (see Appendix). That is, the Series LR circuit cancels the CR circuit formed by the terminators.

Using this idea, the **power supply** that feeds the barrier could look like either of the possibilities in figure 3. In the upper one the raw **power supply** has a connection to ground, which requires that the Series LR circuit be divided between the two network connections. If two separate inductors were to be used, they would each have to be 2.5 mH. But if they are coupled as shown, then each should be 1.25 mH.

The lower circuit of figure 3 assumes that the raw **supply** is isolated.

Notice that, if we tried to use just an inductor alone, it would be quite large, because the frequency range extends down to 50 Hz. A single large resistor also wouldn't work because the circuit would look like only this resistor at 50 Hz. A single small resistor doesn't work either because it would appear in parallel with the terminator resistors at high frequencies. The LR combination is unique in its ability to cancel the terminators in this test circuit.

Isn't There An Active Circuit That Can Do This?

Yes. A gyrator circuit, shown in figure 4, is equivalent to a Series LR circuit. The values shown produce the required 5 mH/50 ohm combination. The **power** transistor is being used to boost the opamp current capability.

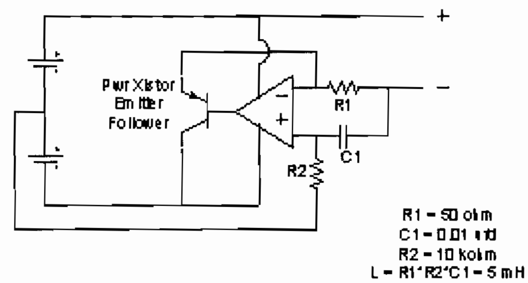


Figure 4 -- Gyrator Generates Series LR

Generally, active circuits will have more components than passive ones, but can be smaller and more flexible. Sometimes they can incorporate non-linearities to settle more quickly in response to load changes. But they can also present greater difficulty in achieving balance. Good isolation of the raw supplies is often the answer.

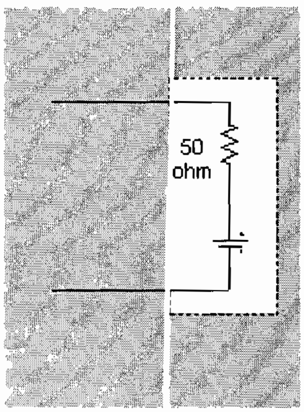


Figure 5 -- **Supply** With Resistor Replacing Both Terminators

Why Not Just Use a Raw Supply with a Series 50 ohm Resistor?

If the Series LR and terminators look like 50 ohm, then why not just use 50 ohm and no terminators, as in figure 5? This would pass the figure 2 test. And it would probably work for smaller networks. (It can certainly be used in bench testing of devices.) The problem is that, for general networks, it doesn't create the correct termination (100 ohm) at both ends of the trunk.

Can I Run More Than One Network From This Supply?

Yes. Several ways of connecting two networks are given in figure 6. Figure 6C is not acceptable, since it causes unbalance. Although figures 6A and 6B are shown with a grounded raw **supply**, an isolated **supply** would also be OK. In figures 6B and 6D the two networks may not be considered separate networks. That is, network 2 would probably be considered just a continuation of network 1. A possible problem with 6B or 6D is that greater direct current through the L and R will be more difficult to achieve. Higher current is considered in a later section. Any of the acceptable arrangements 6A, 6B, and 6D can easily be extended to more than

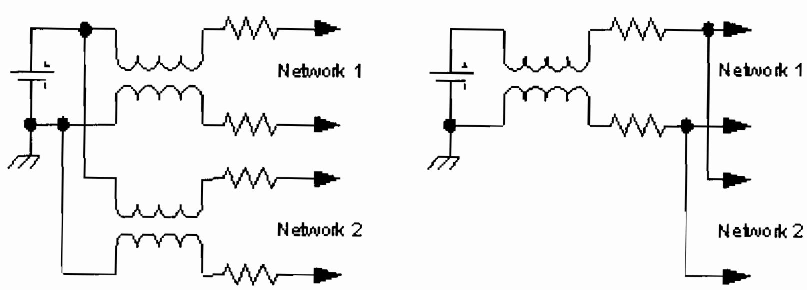
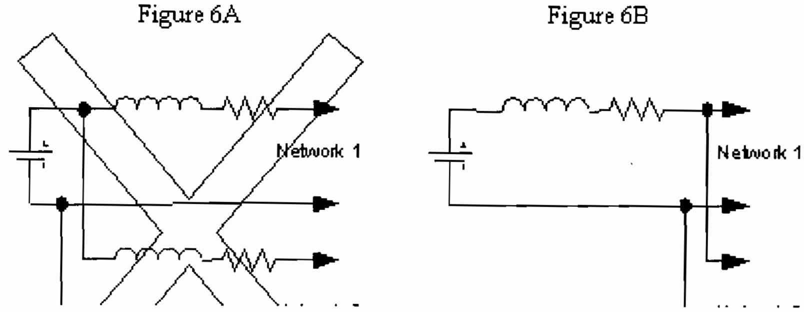


Figure 6A

Figure 6B



two networks.

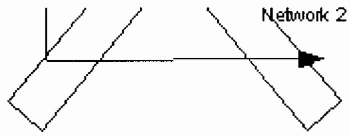


Figure 6C

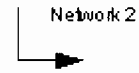


Figure 6D

Is There Anything Special About The Inductor?

Many inductors only need to maintain some minimum inductance to work in their appointed application. This one is effectively a tuning element and can't be too sloppy. Here are some inductor concerns:

1. The inductor has to handle a modest direct current without saturating.

2. The inductor will have some series resistance. You should reduce the series resistor value from 50 ohm to compensate it.

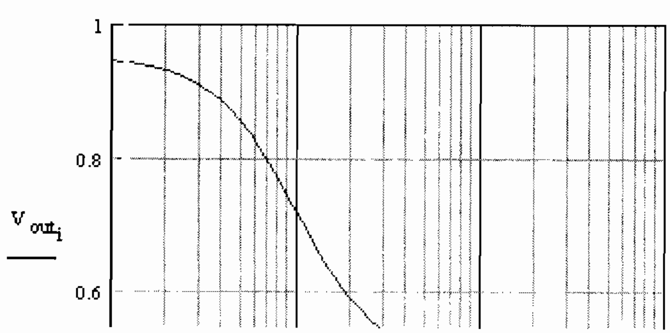
Parasitic capacitance and core loss would normally show up at high frequency. However, in this circuit, capacitance as high as 0.01 ufd and core loss resistance as low as 1000 ohm show little effect. The reason that they don't seems to be that the high-frequency Vout response is being dominated by the two terminators.

Can I Get Rid of the Resistor?

Both the active and passive versions of the Series LR circuit need the 50 ohm resistor. And, in both cases, the full **supply** current has to pass through this resistor. This actually isn't too bad in an intrinsically safe application because the **power supply** doesn't need to **supply** much DC. (The barrier limits current anyway. About 60 or 70 mA is probably the most that has to pass through this resistor.) Later, in the discussion of higher current supplies, we'll look again at removing the resistor.

How About A Supply That Doesn't Feed A Barrier?

The specification for a **supply** that feeds the network (or networks) directly is almost the same as before, except that the frequency range over which the 400 mV pp to 600 mV pp applies is 3 kHz to 39 kHz; and the Rate spec now applies. The Series LR tuning circuit discussed before could still be used. All of the same considerations still apply. But raising the lower frequency from 50 Hz to 3 kHz opens up some more possibilities. Now there's a way to get rid of the inductor.



To create the inductorless version, we just set Z in figure 2 to be a 100 ohm resistor and remove one of the terminators. That is, the **power supply** now includes one of the terminators. The resulting |Vout|

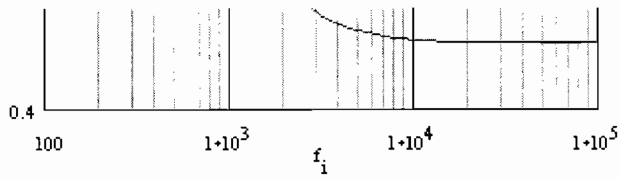


Figure 7 -- |Vout| For Terminator Built Into **Supply**

across the **supply** and single terminator is shown in figure 7. |Vout| for this arrangement is seen to remain within 400 mV to 600 mV at frequencies above 3 kHz. The |Vout| slope is greater than -20 dB/decade from 50 Hz to 3 kHz, so that the Rate spec is also satisfied.

If more than one network is to be powered, then the same considerations apply as in figure 6.

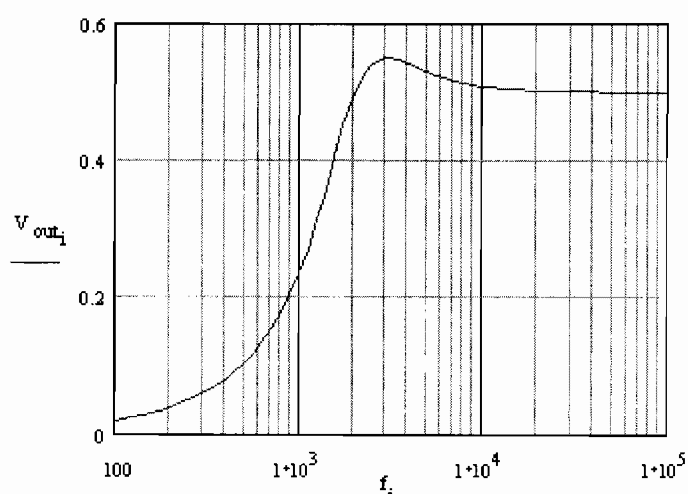
It turns out that if Z in figure 2 is set to 200 ohm and both terminators are used, this works too. But we want to defer discussion of this to the section on current sources.

How Can I Supply A Lot Of Current?

At higher current the Series LR tuning method and the R-only built-in resistor method don't work well because of the high value of R. Suppose that a network has 32 devices each drawing 20 mA for a total of 0.64 amp. Twenty watts are pumped into the 50 ohm resistor. Not only that, but 32 volt is lost across the resistor -- the whole **supply** voltage allowed by **Fieldbus**! Thirty-two devices on one network may not be realistic. But remember that **Fieldbus** isn't like a conventional process control current loop. You could have just one device, such as a mag flow meter, that consumes 500 mA and you'd be in the same boat.

So next we ask the question of whether just an L will work. If we analyze the test circuit of figure 2 using two terminators and just an L (inductor) for the **power supply** impedance, then the

magnitude of the output voltage as a function of frequency looks like figure 8. This is for L = 3 mH. It is apparent that |Vout| is within the target range of 400 mV pp to 600 mV pp for all frequencies above 3 kHz. As L is decreased the peak goes away and eventually at L = 1.9 mH the curve drops below 0.4 volt at 3 kHz. At the other extreme, as L is increased, the peak becomes larger and the curve eventually goes above 0.6 volt at L = 4.0 mH.



The presence of the peak means

that the Rate spec is not

Figure 8 -- Test Circuit Output (Volt pp), L = 3 mH

satisfied. To get rid of it L has to be less than about 2.3 mH. Thus, the acceptable range is 1.9 mH < L < 2.3 mH. A real inductor will have some small amount of DC resistance. A value of 2 ohm is probably not unreasonable for load currents in the region of 0.5 amp. It can be shown that this resistance bends the |Vout| curve upward at low frequencies so that the Rate spec remains satisfied. Therefore, using an L alone works. But the tolerance on L is still quite small (about 10%). In this sense the method is still a "tuning" approach.

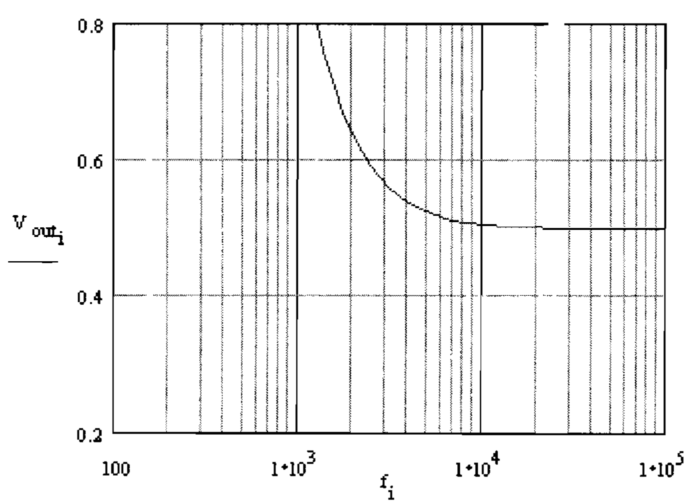
Notice that, although it's OK to use an LR circuit for either the **supply** feeding barrier or **supply** feeding the network directly, it isn't OK to use just the L circuit for a **supply** feeding barrier.

A gyrator can still be used in this L-only approach. But it becomes more difficult to use in high-current situations because R1 in figure 4 must be made very small.

A parallel LR circuit for the Z in figure 2 also appears to work. Using L = 100 mH in parallel with R = 250 ohm yields a test voltage that satisfies both the value and Rate parts of the spec. Despite having a peak, the slope of |Vout| from 50 Hz to 3 kHz remains in the -20 dB/decade to +20 dB/decade range. Therefore, the method satisfies the letter if not the spirit of the specification. If L is made smaller or R larger the peak grows and the rate spec is violated.

The parallel LR is not a tuning method, since it requires only a minimum value of inductance. And if the inductor develops significant losses at high frequency, this may not be too important because we are paralleling it with 250 ohm anyway.

When high currents are combined with significant inductance, a further concern is that the inductor can deliver a nasty voltage transient if disconnected while current is running through it. So it's often a good idea to add a zener diode clamp.



What Else Will Work?

So far we've looked only at cases in which the **power supply** consists of a voltage source in series with some Z. But if the **power supply** were to look like a current source at frequencies of interest, this would also give us the desired result. The **power supply** would appear to be an open circuit and only the terminators would influence the test in figure 2. The resulting plot of |Vout| versus frequency is as in figure 9. At 3 kHz and above, this is within the range of 0.4 volt to 0.6 volt. And, since the load is

Figure 9 -- Vout Magnitude, Current Source **Supply**

primarily just the RC circuit created by the terminators, the Rate spec is satisfied.

It turns out that the current source doesn't have to be a very good one. It can look like 200 ohm and still pass the test. The general effect of this resistance is to pull the curve in figure 9 downward. As the **supply** resistance decreases toward 200 ohm, the flat part of the curve at high frequencies is pulled down toward 0.4 volt. (This means that the Thevenin equivalent of this -- a voltage source in series with 200 ohm -- is also acceptable. We talked about this possibility in an earlier section. But actually using a 200 ohm resistor in this way is probably not very practical because of the large voltage drop and **power** dissipation.)

The current source can't look like a current source at DC, since then the DC voltage would be uncontrolled. Instead, the **supply** must transform itself from a voltage source at DC to a quasi-current source before the frequency reaches 3 kHz.

An active-circuit technique that has been proposed for this is shown in figure 10. The collector (or drain) is connected to the raw **power supply** and the emitter (or source) is connected to the load. The idea behind these circuits is that the capacitor prevents the base-emitter or gate-source voltage from varying at signal frequencies. Therefore, the collector or drain current does not vary at signal frequencies and the device is an open circuit (high impedance).

Experience indicates, however, that these arrangements don't work very well. If the active element of either circuit is modeled simply as a voltage controlled current source, it can be shown that the impedance at high frequencies is just R.

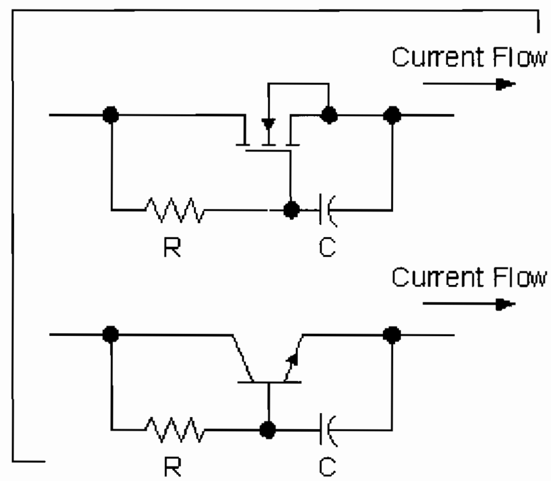


Figure 10 -- Simple Regulators

For the BJT version a rather small R is needed to **supply** enough base current. Another problem with a BJT is its relatively high output conductance (Hoe) which would appear in parallel with R. Hoe can be quite high (output resistance is low), especially in **power** transistors that are large enough to provide some serious current. The 2N6288 [1], for example, is a medium **power** NPN bipolar transistor rated at 40 volt and 7 amp. Its output resistance (=1/Hoe) at a collector current of 1 amp is around 100 ohm. Thus, the parallel combination of R and 1/Hoe is quite small and the BJT version makes a poor current source.

The MOSFET version also has its drawbacks. The output conductance of a MOSFET is usually much smaller than a BJT. But this is true only for relatively large drain-source voltage, where the device is well into saturation. When drain-source voltage equals gate-source voltage, which is what we have in this application, the conductance may still be relatively large. Even assuming that the drain-source (or gate-source) voltage is sufficiently high that conductance isn't a problem, large MOSFETs will have relatively large drain-source and drain-gate capacitances that will bring the conductance back up again at high frequencies. Finally, the MOSFET version ends up dissipating too much **power**. To conduct a significant amount of drain current, the gate-source voltage has to be high. But the gate and drain are tied together at DC and the result is a high dissipation.

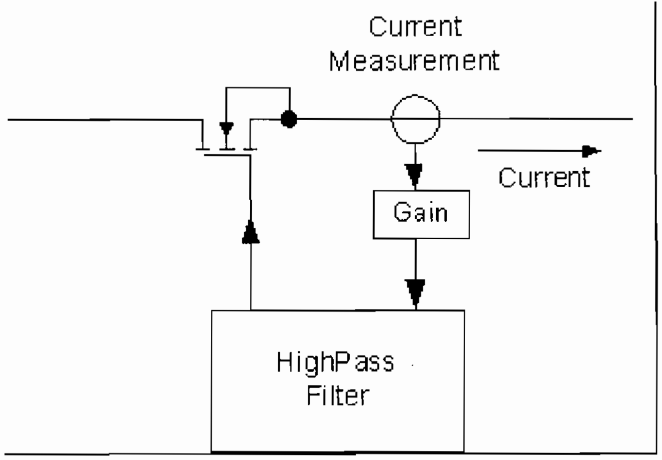


Figure 11 -- Current Source Type of **Supply**

So What's The Answer?

To create a known, consistent impedance we need to abandon these approaches in favor of a complete current regulator, as in figure 11. In effect a high-gain feedback path and highpass **filter** are used to insure that there cannot be fast current changes. Other components have been omitted for clarity.

Although conceptually simple, the arrangement of figure 11 can be difficult in practice. One source of difficulty is the fact that the load, which is the network, is involved in the dynamics of the regulator.

Networks are constructed randomly, so that the load that they represent varies widely. Failure to account for all possible loads may lead to instability in the current regulator.

Another possible source of difficulty is the high-pass **filter**. We may want it to have a steep attenuation slope (many poles). This lets the **power supply** have a relatively fast response to load changes, while the impedance magnitude increases rapidly to a large value at the edge of the signal band. But this, too, may lead to instability.

Some time ago, Analog Services, Inc. recognized these problems and began development of an inductorless add-on circuit that would convert a conventional **power supply** (with voltage regulated output) to the type described here. That is, the impedance is low at DC and rises to about 5 kohm at frequencies used in Foundation **Fieldbus**. The resulting **power supply** meets both the old (clause 11.6) and new (clause 22.6.3.1) impedance requirements. When used with a raw isolated **supply**, the balance conditions are also met. The features of the resulting **supply** are

- 24 volt output at 0 to 1 amp.
- Stable with any combination of 0 to 32 Field Devices, 1 terminator, 2 terminators, and 1900 meter of cable.
- The recovery time with load change is 0.1 second.
- Rate spec is satisfied in the range 50 Hz to 3 kHz.

Note: These are tentative specifications

Analog Services currently licenses this technology. Contact us to learn more about how you can add this to your **power supply**.

Summary

A summary of the methods discussed above is given in the following table.

Type of Supply	Methods	Number Terminators	Component Values (Z in Figure 2)
Feeds Barrier	R as Two Terminators	0*	R = 50 ohm
	Series LR	2	L = 5 mH, R = 50 ohm
	Gyrator	2	Equiv to 5 mH, 50 ohm
Feeds Network Directly	R as Two Terminators	0*	R = 50 ohm
	R as Built-In Terminator	1	R = 100 ohm
	Series LR	2	L = 5 mH, R = 50 ohm
	Gyrator	2	See Text
	L only	2	L = 2.1 mH
	Parallel LR	2	L = 100 mH, R = 250 ohm
	R only	2	200 ohm
	Current Source	2	See Text

*A single R with no terminators is not allowed by network construction rules but can be useful for testing.

References

1. Harris Bipolar Devices Databook SSD-220D, Data Sheet for 2N6288.

Appendix -- Series LR Circuit Cancellation of Terminators

The test impedance consists of a parallel combination of a terminator, a second terminator, and the series LR circuit. The impedance is then given by

$$Z = (R_p + sL_p) \parallel \left(R_T + \frac{1}{sC_T}\right) \parallel \left(R_T + \frac{1}{sC_T}\right) = (R_p + sL_p) \parallel \left(\frac{R_T}{2} + \frac{1}{s2C_T}\right)$$

where Rp and Lp form the series LR circuit, RT is the terminator resistance = 100 ohm, and CT is the terminator capacitance of 1 ufd. This becomes

$$Z = \frac{(R_p + sL_p)\left(\frac{R_T}{2} + \frac{1}{s2C_T}\right)}{R_p + sL_p + \frac{R_T}{2} + \frac{1}{s2C_T}} = \frac{\frac{R_p R_T}{2} + \frac{L_p}{2C_T} + \frac{sL_p R_T}{2} + \frac{R_p}{s2C_T}}{R_p + sL_p + \frac{R_T}{2} + \frac{1}{s2C_T}}$$

If Rp = RT/2 = R and Rp = Lp/(2*R*CT) then

$$Z = \frac{R\left(R + \frac{L_p}{2RC_T} + sL_p + \frac{1}{s2C_T}\right)}{2R + sL_p + \frac{1}{s2C_T}} = R$$

Thus, it is demonstrated that the impedance of the two terminators and the LR circuit are a pure resistance. The inductance value that makes this happen is found as

$$R = \frac{L_p}{2RC_T} \text{ or } L_p = 2R^2C_T = 2(50\ ohm)^2(1ufd) = 5\ mH$$

For more information on how we can help solve your circuit/system problems, call or e-mail us today.

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